Duane's Clinical Ophthalmology

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CO-92

Exhibit A

flaggingly during the waking hours. Clearly, the eye does not accommodate in this manner.

Accommodation may also be mediated through an increase in the power of its refractive elements. The eye may theoretically increase its power through a shortening of the radius of curvature of the cornea of lens or by an axial shift of the lens. Young performed an experiment in which he immersed his eyes in water. The close match of refractive indices for cornea and water eliminated the corneal refractive power thereby making Young an extreme refractive hyperope. In order to see distant objects clearly Young introduced a positive lens to replace the lost corneal power and was able to accommodate for near objects. Thus, he demonstrated that accommodation could be exerted despite the neutralization of the cornea.

The crystalline lens remained as the most logical agent of accommodation. The question to be resolved was whether the crystalline lens moved axially or changed shape. The former possibility was eliminated by the constraints on how much the lens could move within the anterior chamber. Calculations show that the depth of the anterior chamber is not sufficient for maintaining the focus of near objects.

It is indeed the steepening curvatures of the crystalline lens, that account for the ability to accommodate. Helmholtz concluded that the zonule maintains relatively shallow lens curvatures in the unaccommodated state. Relaxation of the fibers, when the ciliary body constricts, allows the elastic capsule of the lens to assume a rounder form. Tscherning noted that the central portion of the lens became more deeply curved while the peripheral zone of the lens surface flattened during accommodation. He concluded that this occurred due to an increase in tension by the zonule during accommodation. It is generally accepted that Helmholtz is correct in concluding that relaxation of tension by the zonule allows the lens to assume a more deeply curved form. Fincham concluded that it was the nonuniform thickness of the lens capsule which caused the bulge in lens curvatures in accommodation rather than capsule elasticity.

Gullstrand provides a radius of curvature of 10 mm for the anterior surface of the crystalline lens when relaxed and a radius of curvature of 5.33 mm when accommodated by nearly 10 D. The axial thickness of the lens slightly increases due to the forward bulge of the anterior surface. The power of the lens increases mainly due to the bulge, going from 19 to 33 D, and the power of the eye correspondingly increases from 58.64 to 70.57 D.

AMPLITUDE AND RANGE OF ACCOMMODATION

When the eye is fully accommodated, the point in space conjugate to the retina is the near point of the eye. It is the nearest point of distinct vision. The amount of accommodation exerted from the relaxed state to full accommodation is termed the amplitude of accommodation. If the distances of the far point and near point from the first principal point of the eye are denoted by r and p and the corresponding reduced vergences are denoted by R and P, the difference of $R - P = A$, in

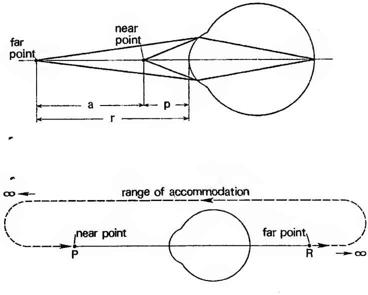


Fig 33-69. Range of accommodation in myopia (top) and hyperopia.

diopters, is the amplitude of accommodation (4). The corresponding distance of distinct vision from the near point to the far point of $p - r = a$ in meters is termed the range of accommodation (Fig 33-69).

The range of accommodation for a given amplitude of accommodation depends on the refractive state of the eye (Table 33-4). An emmetrope, a myope, and a hyperope may each have the same amplitude of accommodation but their ranges of accommodation will greatly differ. To determine the range of accommodation it is necessary to know the refractive state of the eye, ie, the amount of ametropia, and the amplitude of accommodation. From these the far and near points can be calculated. The range of accommodation is the distance between these points. For example, assume that there are three individuals, each with an amplitude of accommodation of 10 D. One is an emmetrope; the second is a 5-D hyperope; and the third is a 5-D myope. What will be their ranges of accommodation?

The far point r of the emmetrope is at infinity, therefore, substitution of these values for R and A into the equation $R - P = A$ results in $0 - P = 10$, or $P = -10$ D.

$$R = \frac{1}{\infty} = 0$$

His amplitude A is given as 10 D. The dioptric value of the near point is -10 D. The near point is located at a distance

$$p = \frac{1}{P}$$

or

$$p = \frac{-1}{10} \text{ meters} = -10 \text{ cm}$$

The range of accommodation of the emmetrope is from 10 cm in front of the first principal plane of the eyes to infinity since, $a = p - r$, where $r = -\infty$; $a = -10 + \infty$.

The 5-D hyperope has a far point which corresponds to the 5 D of hyperopia, or $R = +5$, $A = 10$ D. The far point r is ⅕ meters behind the eye. $P = R - A = 5 - 10 = -5$ D. The near point p is ⅕ meters in front of the eye. In effect 5 D of accommodation were exerted to overcome the hyperopia, so as to see sharply at infinity, the remaining 5 D determined the near point. The range of accommodation of the hyperope is from 20 cm in front of the eyes, through infinity, to 20 cm behind the eyes (Fig 33-69).

TABLE 33-4. Range of Accommodation for a Given Amplitude

Age	Amplitude of Accommodation (Diopters)	Near Point for Emmetrope (cm)
10	14.0	7.0
15	12.0	8.3
20	10.0	10.0
25	8.5	11.7
30	7.0	14.2
35	5.5	18.2
40	4.5	22.2
45	3.5	28.5
50	2.5	40.0
55	1.75	57.0
60	1.00	100.0
65	0.50	200.0
70	0.25	400.00
75	0.0	∞

The dioptric value of the far point of the 5-D myope is $R = -5$. As noted $A = 10$ D.

$$P = R - A$$
$$P = -5 - 10 = -15 \text{ D}$$

The range of accommodation of the myope is

$$a = p - r$$

$$a = -\frac{100}{15} + \frac{100}{5} = -6.7 + 20 = +13.3 \text{ cm}$$

or from 6.7 cm to 20 cm in front of the eyes.

These examples illustrate the limited range of accommodation available to the myope who otherwise has an amplitude of accommodation equal to that of an emmetrope and hyperope.

PRESBYOPIA

The amplitude of accommodation decreases from childhood to age 75. When the reduction in amplitude causes the near point to move beyond the comfortable reading distance the condition is termed presbyopia (old eye). The onset of presbyopia occurs at approximately age 45 when, according to Donders, the amplitude of accommodation is 3.5 D. If a 45-year-old individual is emmetropic his near point will be

$$R - P = A$$
$$0 - P = 3.5$$

and

$$p = \frac{100}{3.5} = 28.5 \text{ cm} = 11 \text{ inches}$$

At age 55 his amplitude has dropped to 1.75 D and his near point is

$$p = \frac{100}{1.75} = 57 \text{ cm} = 22.5 \text{ inches}$$

Ten years later, at age 65 he has only 0.50 D of amplitude and his near point is now

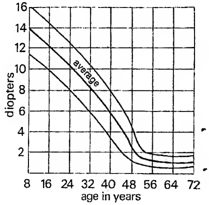
$$p = \frac{100}{0.50} = 200 \text{ cm} = 80 \text{ inches}$$

Finally, at age 75 he has zero amplitude and his near point is at infinity along with his far point. His range of accommodation is zero also. Due to a ¼ D depth of focus he can still see clearly from 4 meters out to infinity.

The relationship between amplitude of accommodation and age was investigated by Donders and was for a long time used as a basis for prescribing a near add. Measurements of monocular amplitude of accommodation were made on 4,000 eyes by Duane. The results shown as an average middle curve and upper and lower ranges on amplitude at any given age are plotted in Figure 33-70 and listed in Table 33-4.

Various causes have been proposed to account for the reduction in accommodative amplitude. There are two parts to accommodation. One is physical and concerns the change in shape of the lens during accommodation. In presbyopia the physical part is related to hardening or sclerosis of the crystalline lens which reduces the elasticity of the lens capsule and the plasticity of the lens core. The physiologic part of accommodation is the innervation and contraction of the ciliary muscles. There is some opinion that sclerosis of the ciliary body reduces its ability to constrict, and the lens does not sufficiently obtain the conditions required for changing its shape. If most of the cause of presbyopia is physical, ie, related to the inability of the crystalline lens to alter its shape to bring near objects into focus, then the lens is an indicator of age and may be considered a biologic clock.

Fig 33-70. Monocular amplitude of accommodation with age for 4,000 individuals. (From Southall JPC: Introduction to Physiological Optics. New York: Dover, 1937, p 89.)



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